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Projected Moiré Fringe 3-D Surface Shape Measuring Method and Device

Technological Field

The invention is about a 3-D surface shape measuring method and device, especially a measuring method and device for absolute measurement of 3-D surface shape by the principle of projected moiré interferometer.

Background Technology

3-D surface shape measuring is a hot issue that attracts attention in engineering and technology circles. The existing 3-D surface shape measuring methods include contact three-coordinates measuring machine and laser three-coordinates measuring machine. Contact three-coordinates measuring machine works through a mechanical probe driven by numerical control system scanning the surface of the measured object, and offers three-dimensional coordinates at every spot of the object. Its measurement accuracy may be above 0.01mm. Given that contact force must be put on the object in mechanical probe scanning and that it takes time for numerical control system to move, Contact three-coordinates measuring machine is slow in measurement. Laser three-coordinates measuring machine replaces mechanical probe by optical probe, and scans the surface of the measured object through laser spot driven by numerical control system. It speeds up measurement at the cost of less space measurement accuracy. However, faster measurement depends on velocity of movement of numerical control system. Thus whole-field measurement will be an ideal choice if much faster measurement is desirable.

Projected moiré refers to the interference fringe formed through interference with sub-grating when main grating is projected onto the surface of the object. Moiré interferometric technique is a whole field, non-contact measuring technique. It has measurement capability possessed by many holographic interferometric techniques and, what's more, it is adjustably sensitive and is free of external interference to good degree. Therefore it has great prospect in engineering application. Image moiré contour initiated by Takasaki and Meadows et al is a promising optical method. Test device for

the method is quite simple: locate the grating close to the object and observing the object through the grating can see fringe pattern. The striated pattern is in some cases surface contour of the object, which can be used to measure surface shape of the object. The method is applicable to measurement of small size objects on the ground that the size of the grating. Another method is respectively initiated by P.Benoit, Y.Yoshino, M.Suzuki and others. The method works by projecting the grating on the object surface and observing moiré contour striated pattern through the other grating. The method is called projected moiré interferometry and is applicable to large size objects. In some conditions, beat fringe between the two gratings will form surface contour for the object, just like contour outlining the land in a contour map. In the early 1980s, image-processing techniques were applied to striated pattern processing, especially striated pattern analysis technique with phase-shift techniques and unwrapping technique as the core makes moiré interferometric technique capable of real-time measurement.

According to deduction by Meadows, Takasaki and Suzukietal, projected moiré striated pattern is the contour of object surface on the condition that the optical centers projection arm and observation arm are in parallel; the spacing of projected grating and observation grating is the same; focal length of lens of projection arm and observation arm is the same; and the distance from projected grating to projected lens is the same as the distance from observation grating to observation lens.

The projected moiré interferometric system is as shown in Chart 1, light source 7 gives off ray of light which passes main grating 2, the grating of main grating 2 is imaged on the measured object 4 through projection lens 3, the measured object 4 is imaged on sub-grating 6 through observation lens and at the same time moiré fringe is imaged on sub-grating 6. Camera 8 records moiré fringe through camera image lens 7.

However, there are two problems puzzling moiré interferometric technique. (1) The contours of the object surface outlined by interferometric fringe are functions of fringe order; altitude difference of contours is not uniformly spaced. It is function of contours, too. Therefore absolute measurement of 3-D surface shape of the object comes after an accurate measurement of absolute fringe order of the interferometric

fringe. (2) The distance from projection optical system and observation optical system to the object (object distance) as well as to projection grating and observation grating (image distance) need to be measured with accuracy. Existing projected moiré interferometric system is unable to define the above parameters so that it cannot be otherwise than regard altitude difference of contours as a constant according to which object distance and image distance are roughly measured. Thus rough measurement of surface shape of the object is called absolute measurement, or accurate measurement of surface shape of the object is called relative measuremed

Purpose of the Invention

The purpose of the invention is to overcome shortcomings of existing measuring method and device for surface shape measuring of projected moiré fringe object and to design a new projected moiré interferometric measuring method and device. Following the mentioned method and device, high-accuracy absolute measurement can be realized through projected moiré interferometric technique while maintaining the quality of real-time measurement of Moiré interferometric technique.

Content of the Invention

To realize the above purpose, the invention adopts the following technique programs: one is projected moiré fringe 3-D surface shape measuring device, which includes projection device with mark point and main grating, observation device with mark point and sub-grating, and two coordinate rectilinear motion axes design to form a right triangle consists of mark points at the position of arbitrary image, mark point of projection device, mark point of observation device, and mark point projected onto object surface by projection device.

Where, the above-mentioned two coordinate rectilinear motion axes, which are formed by mark points and used to measure right triangle, consist of the No.1 rectilinear motion axis with grating ruler, which coincides with optical axis of the observation device and No.2 rectilinear motion axis with grating ruler, which is perpendicular to optical axis of the observation device. The optical axis of projection device and No.2 rectilinear motion axis are crossed as a γ angle. The optical axes of projection device and observation device are crossed as a θ angle. Add θ to γ to

get 90° .

Measuring device described in the invention also includes image capture board, which digitizes image signals and the computer which processes digitized images.

The said projection device includes light source, main grating, mark point and projective image lens. And the said mark point can be behind the main grating or it can be parallel to the main grating.

The said observation device includes measuring beam path and observing beam path, and the said observing beam path includes camera, sub-grating, and a mark point that is parallel to the sub-grating and can be spliced into the beam path as well as movable observer imaging lens.

As to the invention, the said observation device may also include measuring beam path and observation beam path, the said measuring beam path includes camera, sub-grating, movable observer imaging lens; the observation beam path includes a camera that receive the image of mark point, a reflector that is used to change the direction of light by 90°, mark point and a square prism that is behind observer imaging lens and before sub-grating and change the direction of light by 90°.

The projection device in the invention and the main and sub-grating for observation device may be square wave or sine wave. The said mark point may be cross wire or ring.

The said projection device in the invention produces white light through its light source.

The movable projective lens in the said projection device in the invention includes projective lens and linear positioner that pushes it; movable observation lens in the observation device includes observation lens and linear positioiner that pushes it.

Projected moiré fringe 3-D surface shape measuring method involves the following steps:

(1) Form a right triangle with the mark point in the projection device, the mark point in the observation device and the mark point on the object surefire projected by projection device casts onto the object surface;

(2) Determine projection conjugate distance and observation conjugate distance;

(3) Get the projected object distance and image distance as well as observed object distance and image distance;

(4) Automatically focus on projective lens and observation lens according to object distance and image distance, thus forming moiré fringe on the surface of sub-grating;

(5) Determine phase distribution with the mark point projected onto the object as zero-phase by phase-shift algorithm and unwrapping algorithm.

(6) Calculate the height distribution

Namely, the first step is to form a right triangle using the mark point in the projection device, the mark point in the observation device and the mark point cast on the object surface by the projection device; measure projected object distance, projected image distance, observed object distance and observed image distance at some imaging position through two coordinate rectilinear motion axes and mark point in the projection device and observation device; then determine the position of Zero-order fringe through the mark point; the next is to determine fringe order of the surface whole field of the object by phase-shift algorithm and unwrapping algorithm; finally 3-D surface shape of the object can be accurately calculated according to deducted corresponding relations between the height of the object and the projected moiré interference fringe which takes some point in the object as its coordinate reference point.

The said right triangle is formed like this: move the object to fill the view field at observation device, focus the mark point on the object, and align mark point cast on the object with mark point in the observation device.

The said steps for determining projection conjugate distance and observation conjugate distance are as follows: to get the other two sides based on the one given one side and a angle, where, $AE=AD/tg\theta$; $DE=AD/\sin\theta$, θ is the included angle between optical axis of the projection device and optical axis of the observation device, $\theta=arctgR_2/R_1$, AD is the distance between the projection device and the observation device measure by grating ruler (the size is that of No.2 rectilinear motion axis which is a component of right triangle), R_1 and R_2 are respectively moving range of the

gratings, AE, the observation conjugate distance, is the distance between observation device sub-grating and the object, DE, the projection conjugate distance, is the distance between projection device main grating and the object.

Then, get projected object distance and image distance as well as observed object distance and image distance by following equations:

$$Z_C + Z_{CF} = \frac{AD}{tg\vartheta} \qquad \frac{1}{Z_C} + \frac{1}{Z_{CF}} = \frac{1}{F_1}$$

$$L_p + L_{PF} = \frac{AD}{\sin\vartheta} \qquad \frac{1}{L_P} + \frac{1}{L_{PF}} = \frac{1}{F_2}$$

Where, Z_C is the observed object distance, Z_{CF} is the observed image distance; L_{PF} is focal length of the observation device and F_2 is focal length of the projection device.

The invention is on the ground that the process of automatic focusing of the projected object distance and image distance as well as the observed object distance and image distance is the process of moving the projective lens and observation lens to the image position, as s result of which moiré fringe can be formed on grating surface of the observation device.

Height distribution is finally calculated by the following formulas:

$$Z = -\frac{(\frac{\varphi}{2\pi f} + X_C)D - L_{PF}B}{(\frac{\varphi}{2\pi f} + X_C)C - L_{PF}A}$$

$$X_Z = \frac{Z + Z_C}{Z_{CF}} X_C$$

$$Y_Z = \frac{Z + Z_C}{Z_{CF}} Y_C$$

Where, X_Z, Y_Z, and Z are position coordinates of some points on the object, f is grating frequency, and Φ is the phase.

$$A = Z_C Z_{CF} \sin\theta + Z_C X_C \cos\theta \qquad B = Z_C^2 X_C \cos\theta$$

$$C = Z_C Z_{CF} \cos\theta - Z_C X_C \sin\theta \qquad D = -Z_C^2 X_C \sin\theta + Z_C Z_{CF} L_P$$

The following is description of the invention with the help of charts and embodiments; the described embodiments are for description instead of restriction of the invention.

Brief Description of the Invention

Chart 1 is a sketch of existing projected moiré interferometric measuring system

Chart 2 is a sketch of the invention, namely, projected moiré fringe 3-D surface shape measuring device;

Chart 3 is a sketch of the projection device of an embodiment for 3-D surface shape measuring device;

Chart 4 is the sketch of observation device of an embodiment for 3-D surface shape measuring device;

Chart 5 is a sketch of parameter calculation;

Chart 6 is a sketch of measurement principle of projected moiré interference fringe;

Chart 7 is a flow chart of projected moiré fringe 3-D surface shape measuring method;

Chart 8 is a sketch of the projection device of another embodiment for 3-D surface shape measuring device;

Chart 9 is a sketch of observation device of another embodiment for 3-D surface shape measuring device;

Refer to Chart 2, the invention projected moiré fringe 3-D surface shape measuring device is composed of observation device 20, No.1 rectilinear motion axis 40 in the direction of optical axis of observation device and No.1 grating ruler 60, rotary stage 30 that is on the slider of No.1 rectilinear motion axis 40 and measured object 80 that is fixed on rotary stage 30, No.2 rectilinear motion axis 50 and No.2 grating ruler 70 that is perpendicular to No.1 rectilinear motion axis 40, projection device 10 whose optical axis and rectilinear motion axis 50 are crossed as a γ angle, marble platform 90 that locates No.1 rectilinear motion axis 40 and No.1 grating ruler 60, No.2 rectilinear motion axis 50 and No.2 grating ruler 70, and observation device 20. The said measuring device includes also image capture board used to digitize image signals and computer 110 that processes digitized images.

Projection device 10 may be as is shown in Chart 3, including light source 11 which is before condenser 12, main grating 13 which is before mark point 14, and

projective lens 15. Linear positioner 17 controls movement of main grating 13 within the grating surface, movement of projection device 15 in the direction of optical axis is controlled by linear positioner 16.

In projection device 10, the main grating and mark point can be parallel as is shown in Chart 8.

Observation device 20 includes measuring beam path, and the said measuring beam path includes camera 21, sub-grating mark point switch 23 and movable observer imaging lens 29.

As is shown in Chart 9, measuring beam path includes camera 21, which receives moiré fringe on the sub-grating and camera-imaging lens 22, sub-grating mark point switch 23 and movable observer-imaging lens 29. Movement of observation lens 29 in the direction of optical lens is controlled by linear positioner 29A.

Observation device 20 can also consist of measuring beam path and observation beam path, as showed in Chart 4. The said observation beam path includes observation lens 29, linear positioner 29A that controls the movement of observation lens 29 along optical axis, square prism 24 that vertically split light from the measuring beam path and is located behind imaging lens 29 and in front of sub-grating 23, mark point 25 located between square prism 24 and reflector 26, reflector 26 that changes the direction of the beam path to 90 degrees, observation camera 28 and observation camera imaging lens 27 of the imaging mark point 25. The said measuring beam path consists of observation lens 29, linear positioner 29A that controls the movement of observation lens 29 along optical axis, sub-grating 23, camera 21 and camera imaging lens 22 used for receiving moiré fringes on the surface of sub-grating.

See the flow chart for projected moiré fringe 3-D surface shape measuring method of this invention in Chart 7. In measuring, firstly move the measured object 80 along No.1 rectilinear motion axis 40 to the place nearest to observation device 20. Adjust the imaging lens of projection device 10 to let the mark point clearly imaged on the surface of measured object 80. Adjust the imaging lens of observation device 20 to get clear images of object 80 and the mark point on it. Move projection device 10 along No.2 rectilinear motion axis 50 to make the mark point projected on object 80

superposed with the mark point inside observation device 20. Then projection device's mark point, observation device's mark point and the mark subpoint on the object form a triangle ABC (as in Chart 5). ABC is a right-angled triangle because No.1 rectilinear motion axis 40 and No.2 rectilinear motion axis 50 are crossed as a right angle, in addition that the cross line AB of projection device's mark point and observation device's mark point is superposed with the movement direction of No.2 rectilinear motion axis 50. In the right-angled triangle ABC, measure the right-angled side AB and the angle θ between the optical axes of the projection and observation device. Then reset the first grating ruler 60 and the second grating ruler 70. Move the object along No.1 rectilinear motion axis 40 to point E and the movement amount of the first grating ruler 60 is R_1. Move projection device 10 to point D and the movement amount of the second gratin ruler 70 is R_2. Then projection device's mark point, observation device's mark point and the reference point E on the object constitute a new right-angled triangle ADE. If the focal length of observation lens is F_1, object distance is Z_C, image distance is Z_{CF}, focal length of projective lens is F_2, object distance is L_P and image distance is L_{PF}, then:

$$AD = AB + R_2 \qquad (1)$$

$$\frac{1}{Z_C} + \frac{1}{Z_{CF}} = \frac{1}{F_1} \qquad (2)$$

$$Z_C + Z_{CF} = \frac{AD}{\mathrm{tg}\,\vartheta} \qquad (3)$$

$$L_p + L_{PF} = \frac{AD}{\sin \vartheta} \qquad (4)$$

$$\frac{1}{L_P} + \frac{1}{L_{PF}} = \frac{1}{F_2} \qquad (5)$$

Evaluate Z_C and Z_{CF} according to equation (2) and (3) and evaluate L_{PF} and L_P according to equation (4) and (5). Then start automatic focusing.

Move projective lens of projection device 10 to L_{PF} to let the beam sent out by the projection device's light source clearly imaged on the measured surface 80 after getting across the main grating. Move the imaging lens of observation device to Z_{CF} to

make the measured surface 80 and the grating line projected on it clearly imaged on the sub-grating and form interference fringe on the sub-grating. The interference fringe is moiré fringe. The camera input the moiré fringe image into the image capture board 100. Digitized fringe image is inputted into computer 110. Hence a digitized interference fringe image comes into being. Move the main grating and make the receiving camera sample 4 fringe images respectively when the grating moves along the direction vertical to the optical axis to points at a quarter, a half and three quarters of the grating spacing. Input the fringe images into computer 110 through image capture board 100 and use phase-shift algorithm to get the phase diagram from 0 to 2π.

$$I_1 = I_0 + A\sin(\varphi + 0)$$

$$I_2 = I_0 + A\sin(\varphi + \pi\frac{1}{2}) \qquad (7)$$

$$I_3 = I_0 + A\sin(\varphi + \pi) \qquad (8)$$

$$I_4 = I_0 + A\sin(\varphi + \frac{3\pi}{2}) \qquad (9)$$

$$\varphi = tg^{-1}\frac{I_4 - I_2}{I_1 - I_3} \qquad (10)$$

Where, I_0 is ambient light intensity, A is fringe contrast and ω is the phase of each point.

Then use unwrapping algorithm to evaluate the phase diagram. Its principle is as follow:

Judged from the criterion that if φ_2-φ_1 π, then φ_2=φ_1-2π; if φ_2-φ_1 $-\pi$ then φ_2=φ_1+2π, the phase diagram after phase-shift can be unwrapped to continuously changed phase distribution.

If observed object distance Z_C, observation image distance Z_{CF}, projection image distance L_{PF}, projected object distance L_P, the optical center angle θ of projection device and observation device, and grating spacing P_P=P_C=P are all given, the height distribution of the measured object can be calculated with deductive projected moiré height and phase formula.

For general use of the formulas, the lines connecting the optical centers of main grating and sub-grating form a random triangle.

Establish the coordinate system on the projected grating, reference plane and reference grating respectively as that shown in Chart 6. We can assume that the projected grating spacing is P_P (or the spatial frequency is f_P), and that the reference grating spacing is P_C (or the spatial frequency is f_C).

The equation of the projected grating is: $I_P = \sin(2\pi f_P X_P)$ (11) .

(We can assume that the initial phase is zero. In the event of being in other non-sinusoidal forms, the calculation can be conducted with Fourier order.)

On the reference plane, as X corresponds to X_P, the following relation will be obtained.

$$tg\alpha = \frac{X_P}{L_{PF}} \qquad (12)$$

$$\frac{X}{\sin\alpha} = \frac{L_P}{\sin(\frac{\pi}{2} - \theta + \alpha)} = \frac{L_P}{\cos\theta\cos\alpha + \sin\theta\sin\alpha} \qquad (13)$$

Namely, $X = \frac{L_P}{\cos\theta ctg\alpha + \sin\theta}$

We can get the Equation 14 from Equations 12 and 13:

$$X_P = \frac{XL_{PF}\cos\theta}{L_P - X\sin\theta} \qquad (14)$$

From the equation above, we can find that there is a non-lineal relationship between X_P and X, which leads to the occurrence of distortion of grating projected on the reference plane. The grating will not be equal-spaced any more. The equation thereof can be expressed as follows:

$$I = I_P = \sin(2\pi f_P \frac{XL_{PF}\cos\theta}{L_P - X\sin\theta}) \qquad (15)$$

This is the equation for the grating on the reference plane.

Let's turn to receiving system. For that, the image of the projected grating is formed at the plane where the reference grating is located. We can find that $\frac{X}{Z_C} = \frac{X_C}{Z_{CF}}$ (16) by reference to the figure, that is to say, $X = \frac{Z_C}{Z_{CF}} X_C$ (17).

Substitute Equation 17 into 15, we can get the following equation for the light intensity distribution of the projected grating image formed at the reference grating plane:

$$I_C = \sin(2\pi f_P \frac{X_C Z_C L_{PF}\cos\theta}{Z_{CF}L_P - Z_C X_C \sin\theta}) \qquad (18)$$

If the equation for reference grating is $I_{CR}=\sin(2\pi f_C X_C + \Delta)$ (19), then we can get the equation for the mixed light intensity distribution (moiré fringe) formed by I_C and I_{CR} as the following:

$$I_{CCD} = I_C \times I_{CR} = \sin(2\pi f_P \frac{X_C Z_C L_{PF}\cos\theta}{Z_{CF}L_P - Z_C X_C \sin\theta}) \times \sin(2\pi f_C X_C + \Delta)$$
$$= \frac{1}{2}\left\{\cos\left[2\pi f_P \frac{X_C Z_C L_{PF}\cos\theta}{Z_{CF}L_P - Z_C X_C \sin\theta} - (2\pi f_C X_C + \Delta)\right] - \cos\left[2\pi f_P \frac{X_C Z_C L_{PF}\cos\theta}{Z_{CF}L_P - Z_C X_C \sin\theta} + (2\pi f_C X_C + \Delta)\right]\right\} \qquad (20)$$

When adopting the projected moiré method for shape testing, the structure of the grating cannot be recognized by CCD for individual I_C and I_{CR} requirements. In Formula 20, the second item is a high frequency one that cannot be recognized by CCD. The optical field is uniform. CCD can only recognize the low frequency fringe in the first item. Therefore, the equation can be expressed as follows:

$$I_{CCD} = \frac{1}{2}\cos\left[2\pi f_P \frac{X_C Z_C L_{PF}\cos\theta}{Z_{CF}L_P - Z_C X_C \sin\theta} - (2\pi f_C X_C + \Delta)\right] \qquad (21)$$

Where, generally $f_P = f_C = f$.

If the object is placed behind the reference plane as shown in Chart 6, and select Point O to coincide with certain point of this object (mark point, i.e., the height of this point thereof), then we can get:

$$\frac{X'}{Z_C} = \frac{X - X' - \Delta X}{Z} = \frac{X - \Delta X}{Z + Z_C} = \frac{X_Z}{Z + Z_C} \qquad (22)$$

$$X' = \frac{Z_C}{Z + Z_C}(X - \Delta X) \qquad (23)$$

By reference to the geometrical relationship in the figure, we can get $\frac{Z}{\Delta X} = tg(\frac{\pi}{2} - \theta + \alpha)$, i.e. $\Delta X = Z\frac{1 - ctg\theta tg\alpha}{ctg\theta + tg\alpha}$ (24).

Equation 24 can be converted into $\Delta X = Z\frac{\sin\theta - \cos\theta\, tg\alpha}{\cos\theta + \sin\theta\, tg\alpha}$ (25).

We can get the equation $X = \frac{L_P tg\alpha}{\cos\theta + \sin\theta\, tg\alpha}$ (26) from Equation 13.

The following simplified equation can be obtained by substituting Equation 25, 26 and 12 into Equation 23:

$$X_P = L_{PF} \times \frac{X'(Z+Z_C)\cos\theta + ZZ_C\sin\theta}{Z_C L_P + ZZ_C\cos\theta - X'(Z+Z_C)\sin\theta} \qquad (27)$$

As $X' = \frac{Z_C}{Z_{CF}} X_C$, we can get the following equation by substituting it into Equation 27:

$$X_P = L_{PF} \times \frac{Z_C X_C(Z+Z_C)\cos\theta + ZZ_C Z_{CF}\sin\theta}{Z_C Z_{CF} L_P + ZZ_C Z_{CF}\cos\theta - Z_C X_C(Z+Z_C)\sin\theta} \qquad (28)$$

Light intensity distribution of projected grating image that is imaged onto reference grating surface can be as follows after the modulation of Height Z:

$$\begin{aligned} I_C &= \sin\left(2\pi f_P \times L_{PF} \times \frac{Z_C X_C(Z+Z_C)\cos\theta + ZZ_C Z_{CF}\sin\theta}{Z_C Z_{CF} L_P + ZZ_C Z_{CF}\cos\theta - Z_C X_C(Z+Z_C)\sin\theta}\right) \\ &= \sin\left(2\pi f_P \times L_{PF} \times \frac{Z(Z_C Z_{CF}\sin\theta + Z_C X_C\cos\theta) + Z_C^2 X_C\cos\theta}{Z(Z_C Z_{CF}\cos\theta - Z_C X_C\sin\theta) - Z_C^2 X_C\sin\theta + Z_C Z_{CF} L_P} \qquad (29)\right. \end{aligned}$$

In reference to grating equation it can also be written as $I_{CR} = \sin(2\pi f_C X_C + \Delta)$ (9), it can be deducted through $I_{CCD} = I_C \times I_{CR}$ and indistinguishable of high frequency grating structure that :

$$I_{CCD} = \frac{1}{2}\cos\left[2\pi f_P L_{PF} \frac{Z(Z_C Z_{CF}\sin\theta + Z_C X_C\cos\theta) + Z_C^2 X_C\cos\theta}{Z(Z_C Z_{CF}\cos\theta - Z_C X_C\sin\theta) - Z_C^2 X_C\sin\theta + Z_C Z_{CF} L_P} - (2\pi f_C X_C + \Delta)\right] \qquad (30)$$

Generally we takes $f_p = f_c = f$. As to formula (30), if $Z = 0$, it can be reduced to formula (21), which also indicates the accuracy of the above deduction.

Where, phase can be written as:

$$\varphi = 2\pi f_P L_{PF} \frac{ZA+B}{ZC+D} - (2\pi f_C X_C + \Delta) \qquad (31)$$

Where,

$$A = Z_C Z_{CF}\sin\theta + Z_C X_C\cos\theta \qquad B = Z_C^2 X_C\cos\theta$$

$$C = Z_C Z_{CF}\cos\theta - Z_C X_C\sin\theta \qquad D = -Z_C^2 X_C\sin\theta + Z_C Z_{CF} L_P$$

As to formula (31), calculate gird origin phase: $X_C=0$, $Y_C=0$, $Z=0$, and when substituted into (21) we can get $\varphi_O = -\Delta$, which can be eliminated on the ground that it is a constant added to all phases, and the next step is to do as follows:

$$\varphi = \varphi - \varphi_O \qquad (31-1),$$

Here the whole-field phase can be written as:

$$\varphi = 2\pi f_P L_{PF} \frac{ZA+B}{ZC+D} - 2\pi f_C X_C \qquad (32)$$

If $f_P = f_C = f$, Z can be:

$$Z = -\frac{(\frac{\varphi}{2\pi f} + X_C)D - L_{PF}B}{(\frac{\varphi}{2\pi f} + X_C)C - L_{PF}A} \qquad (33)$$

Combine formula (22) and (17) we can get:

$$X_Z = \frac{Z+Z_C}{Z_C}X' = \frac{Z+Z_C}{Z_C} \bullet \frac{Z_C}{Z_{CF}}X_C = \frac{Z+Z_C}{Z_{CF}}X_C \qquad (34)$$

The proportional relation that X_Z is involved is true to Y_Z, thus

$$Y_Z = \frac{Z+Z_C}{Z_{CF}}Y_C \qquad (35)$$

A complete formula(X_Z, Y_Z, Z)can be deducted through the above deduction:

$$Z = -\frac{(\frac{\varphi}{2\pi f} + X_C)D - L_{PF}B}{(\frac{\varphi}{2\pi f} + X_C)C - L_{PF}A}$$

$$X_Z = \frac{Z+Z_C}{Z_{CF}}X_C \qquad (36)$$

$$Y_Z = \frac{Z+Z_C}{Z_{CF}}Y_C$$

In application to the above formula, it is necessary to change the height first and when height distribution is derived, to change the position by the last two formulas in (36) in order to derive X_Z and Y_Z; through repeatedly doing that, 3-D object surface shape will finally become clear.

Implementation Program

Embodiment example 1

Showed as Chart 2, observation device 20 is fixed on the marble platform 90. Made by Japan THK Company and driven by a hand wheel, rectilinear motion axis 40 (comes with dust cover) with the length of 1,000 mm is fixed along the direction of the optical axis of observation device 20. Rotary stage 30 is fixed on the slider of the rectilinear motion axis and can make 360-degree rotation. The measured object, aviation engine blade 80 is fixed on the rotary stage 30. The first grating ruler 60 is fixed parallel with No.1 rectilinear motion axis 40. Made by Japan THK Company and driven by a hand wheel, No.2 rectilinear motion axis 50(with dust cover)with the length of 400 mm is fixed vertically to No.1 rectilinear motion axis 40. Projection device 10 is fixed on the slider of No.2 rectilinear motion axis 50. The optical axis of projection device 10 and No.2 rectilinear motion axis 50 are crossed as a γ angle. The second grating ruler 70 is fixed parallel to No.2 rectilinear motion axis 50. Projection device 10 is connected with power supply190 through cable C07. The measuring camera 21 and observation camera 28 of observation device 20 are connected with Matrox Pulser four-channel image capture board 100 through cable C08 and cable C09. Image capture board 100 is plugged into computer 110. Projective lens linear positioner 16 for projection device 10 is linear positioner M224.20 and grating for linear positioner 17 is linear positioner M222.20, both made by German PI Company. Observer imaging lens linear positioner 29A of for observation device 20 is German PI Company's linear positioner M224.20. They are respectively connected with German PI Company's Four-channel DC electric machine control panel 180(C—842.40) through cable C01, C02 and C03. Control panel 180 is plugged into computer 110.

Showed as Chart 3, projection device 10 consists of light source11 in front of condenser 12, main grating 13 in front of the mark point, cross wire 14, and projective lens 15. Linear positioner 17 controls the movement of main grating 13 within the grating surface, and linear positioner 16 controls the movement of projective lens 15 along the direction of optical axis.

Showed as Chart 4, observation device 20 consists of measuring beam path and

observation beam path. The said observation beam path consists of observation lens 29, linear positioner 29A that controls the movement of observation lens 29 along the optical axis, square prism 24 located behind observation lens 29 and in front of sub-grating 23 that vertically splits light from measuring beam path, mark point---cross wire 25 located between square prism 24, reflector 26 that changes the light route for 90 degrees, observation camera 28 and observation camera imaging lens 27 for imaging mark point---cross wire 25. The said measuring beam path consists of observation lens 29, linear positioner 29A that controls the movement of observation lens 29 along optical axis, sub-grating 23, camera 21 and camera imaging lens 22 used for receiving moiré fringes on the surface of sub-grating.

In measuring, move projective imaging lens linear positioner 16 at first, and let projective lens15 form a clear image of cross wire 14. Adjust observation device imaging lens linear positioner 29A, and make the cross wire clearly imaged onto the target of observation camera 28 when imaged onto the object through projective imaging lens15. Adjust No.2 rectilinear motion axis50 to make the image of crosswire onto the object superposed with the image of observation device cross wire 25. After following Chart 7 to carry through step (2) (3) (4), start automatic focusing, that is, adjust projective imaging lens linear positioner 16 to make projective lens 15 get a clear image of grating 13. Fine adjust observer imaging lens linear positioner 29A to make observation lens29 form a clear image of the image projected by grating 13 onto the subject. According to step (5) (6) (7) (8) in Chart 7, move the main grating and make the observation camera sample 4 fringe images respectively when the grating moves along the direction vertical to the optical axis to places at a quarter, a half and three quarters of the grating distance. Input the moiré fringe images into image capture board 100 and digital fringe images into computer 110 with the camera, and a digitized chart of interference fringe comes into being. Use phase-shift algorithm to get the phase diagram from 0 to 2π. Finally use the zero phase of mark point and calculate the height distribution of the object. Repeat as above and evaluate Xz, Yz and Z of every point, and then get the surface shape of 3-D object. The measurement accuracy is ±0.01mm.

Embodiment Example 2

Showed as Chart 2, observation device 20 (observation device as shown in Chart9) on the marble platform 90. Made by Japan THK Company and driven by a hand wheel, rectilinear motion axis 40 (comes with dust cover) with the length of 1,000 mm is fixed along the direction of the optical axis of observation device 20. Rotary stage 30 is fixed on the slider of the rectilinear motion axis and can make 360-degree rotation. The measured object, aviation engine blade 80 is fixed on the rotary stage 30. The first grating ruler 60 is fixed parallel with No.1 rectilinear motion axis 40. Made by Japan THK Company and driven by a hand wheel, No.2 rectilinear motion axis 50(comes with dust cover) with the length of 400 mm is fixed vertically to No.1 rectilinear motion axis 40. Projection device 10 is fixed on the slider of No.2 rectilinear motion axis 50. The optical axis of projection device 10 and No.2 rectilinear motion axis 50 are crossed as a γ angle. The second grating ruler 70 is fixed parallel to No.2 rectilinear motion axis 50. Projection device 10 is connected with power supply190 through cable C07. The measuring camera 21 of observation device 20 is connected with four-channel image capture board 100 through cable C08. Image capture board 100 is plugged into computer 110. Projective lens linear positioner 16 for projection device 10 is linear positioner M224.20 and grating linear positioner 17 is linear positioner M222.20, both made by German PI Company. Observer imaging lens linear positioner 29A for observation device 20 is German PI Company's linear positioner M224.20. They are respectively connected with German PI Company's Four-channel DC electric machine control panel 180 (C—842.40) through cable C01, C02 and C03. Control panel 180 is plugged into computer 110.

Showed as Chart 8, projection device10 consists of light source 11, condenser 12, main grating ring switch 13, projective lens 15, projective lens linear positioner 16 and grating linear positioner 17

Showed as Chart 9, observation device 20 consists of measuring camera21, imaging lens22 of the measuring camera, sub-grating ring switch 23, observer imaging lens29, and observer imaging lens linear positioner 29A.

In measuring, make the ring of projection device main grating ring switch 13 splice into the beam path. Move projective imaging lens linear positioner 16 to make imaging lens15 get a clear image of imaging lens15. Make the ring of observation device sub-grating ring switch 23 splice into the beam path. Adjust the observer imaging lens linear positioner 29A and the short guide rail to make the imaged ring imaged onto the target of measuring camera21 superposed with the ring of observation device. Then start automatic focusing after carrying through step (2) (3) (4) in Chart7. Make the main grating of grating ring switch 13 of projection device10 and the sub-grating of sub-grating ring switch 23 of observation device 20 splice into the beam path. Follow step (5) (6) (7) (8) of Chart7, and get the surface shape of the 3-D object. For details refer to embodiment example1. The measurement accuracy is ±0.01mm.

With the projected moiré fringe 3-D surface shape measuring device and method in this invention, use moiré fringe interference device and method to form moiré fringe image containing the surface height distribution information of the measured object. Input the luminous intensity data of optical images collected by the camera into the computer with the image capture board. After digitized pretreatment for moiré fringe images by the computer, use phase-shift algorithm to deal with the moiré fringe images after phase-shift, and get the phase diagram with measured object's surface height information expressed in numerical value and X, Y, Z coordinate value of all points on the surface of the measured object. Then 3-D surface shape measuring for the object is finished, dynamic 3-D surface shape of the measured object is displayed and the measured data of the surface shape is outputted. The invention realizes the absolute measurement of 3-D object surface shape measurement under whole field with high measurement accuracy of ±0.01mm, 5-10 times that of the existing measuring device, and can accomplish the measuring in 30s. It is applicable for the high-precision and high-speed measurement of 3-D objects with complex shape such as a engine.